AN-240
Application Note

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SCR POWER CONTROL FUNDAMENTALS

Prepared by

Applications Engineering

Recent high volume production techniques have brought SCR prices down to the point that almost any electrical product can benefit from electronic control. But how? What do SCR's do? How are they applied? This article takes a look at some fundamentals of power control using these devices.

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INTRODUCTION

Recent high volume production techniques have brought SCR prices down to the point that almost any electrical product can benefit from electronic control. But how? What do SCRs do? How are they applied? Let's take a look at some fundamentals of power control using these devices.

OUTPUT POWER CHARACTERISTICS

The most common form of SCR power control is phase control. In this mode of operation, the SCR is held in an "off" condition (in which the SCR blocks all current flow in the circuit except for a small milliampere leakage current) for a portion of the positive half cycle and then is triggered into an "on" condition at a time in the half cycle determined by the control circuitry (in which the circuit current is limited only by the load – the entire line voltage except for a nominal one volt drop across the SCR is aplied to the load).

One SCR alone can control only one half cycle of the waveform. For full wave AC control, two SCR's are connected in inverse parallel (the anode of each connected to the cathode of the other). For full wave DC control, two methods are possible. Two SCR's may be used in a bridge rectifier or one SCR may be placed in series with a diode bridge (see Figure 1).

Figure 2 shows the voltage waveform along with some common terms used in describing SCR operation. Delay angle is the time, measured in electrical degrees, during which the SCR is blocking the line voltage. The period during which the SCR is on is called the conduction angle.

It is important to note that the SCR is a voltage controlling device. The load and power source determine the circuit current.

Now we arrive at a problem. Different loads respond to different characteristics of the AC waveform. Some loads are sensitive to peak voltage, some to average voltage and some to r. m. s. voltage. Figures 3 and 4 show the various characteristic voltages plotted against the conduction angle for half wave (Figure 3) and full wave (Figure 4) circuits. These voltages have been normalized to the r. m. s. of the applied voltage. To determine the actual peak, average or r. m. s. voltage for any conduction angle, we simply multiply the normalized voltage by the r.m.s. value of the applied line voltage. (These normalized curves also apply to current in a resistive circuit.) Since the greatest majority of circuits are either 115 or 230 volt power, the curves have been redrawn for these voltages in Figures 5 and 6.

A relative power curve has been added to Figures 3 and 4 for constant impedance loads such as heaters. (Incandescent lamps and motors do not follow this curve precisely since their relative impedance changes with applied voltage.) To use the curves, we find the full wave rated power of the load, then multiply by the fraction associated with the phase angle in question. For example, a 180° conduction angle in a half wave circuit provides 0. 5 x full wave full-conduction power.

An interesting point is illustrated by the power curves. A conduction angle of 30° provides only three per cent of full power in a full wave circuit, and a conduction angle of 150° provides 97 per cent of full power. Thus, the control circuit can provide 94 per cent of full power control with a pulse phase variation of only 120°. Thus, it becomes pointless in many cases to try to obtain conduction angles less than 30° or greater than 150°.

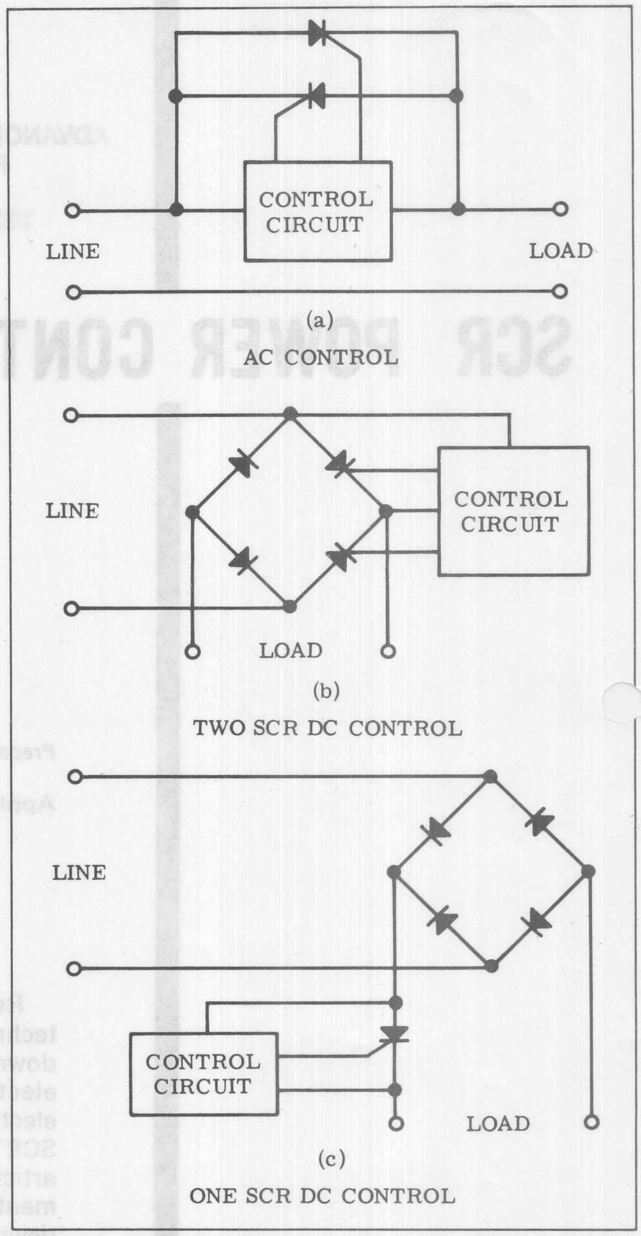

FIGURE 1 — SCR CONNECTIONS FOR VARIOUS METHODS OF PHASE CONTROL

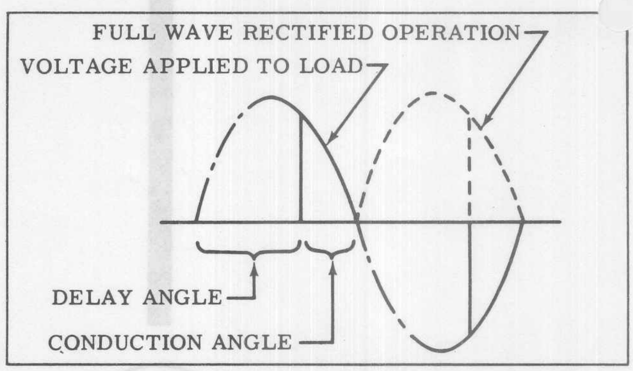

FIGURE 2 — SINE WAVE SHOWING PRINCIPLES OF PHASE CONTROL

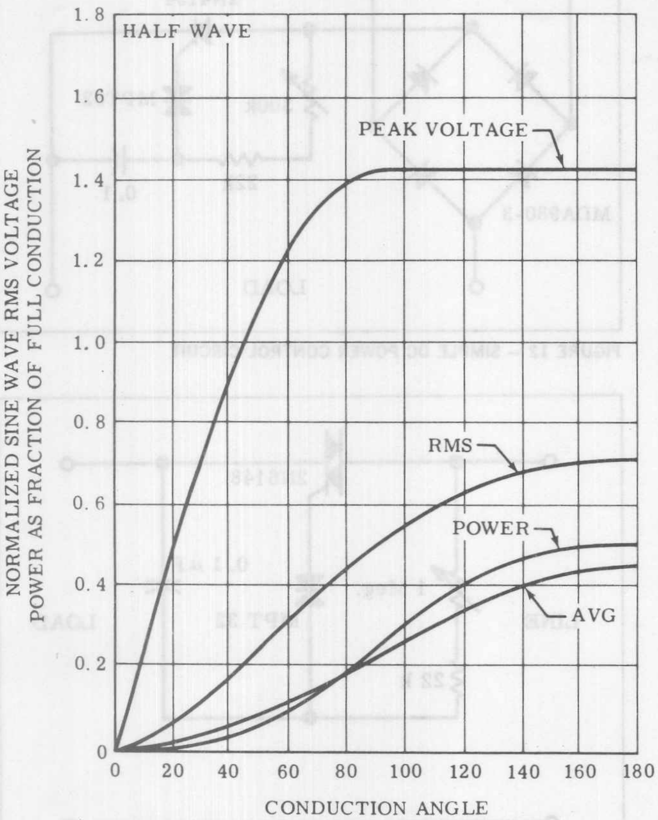

FIGURE 3

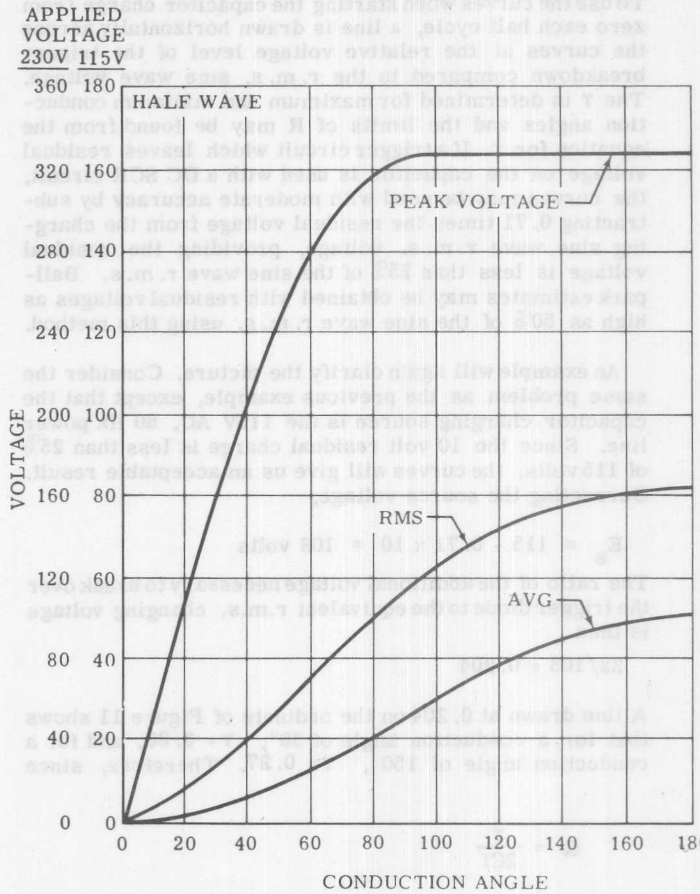

FIGURE 5

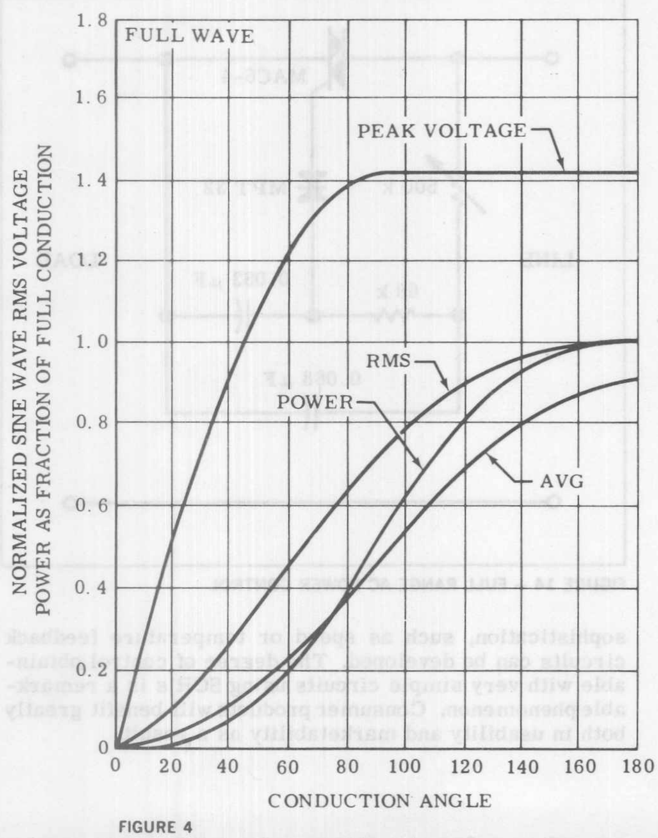

FIGURE 4

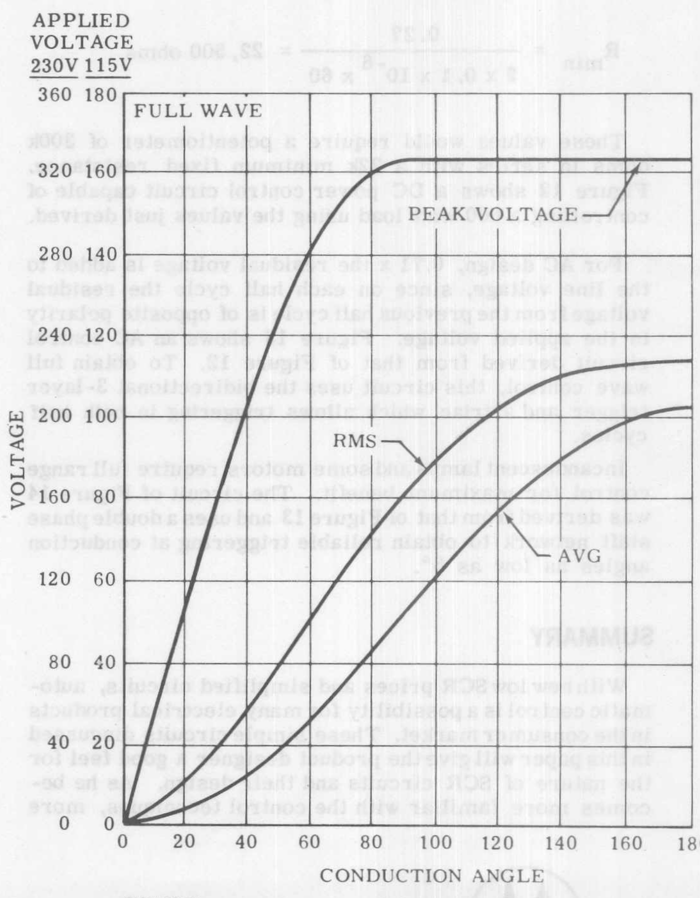

FIGURE 6

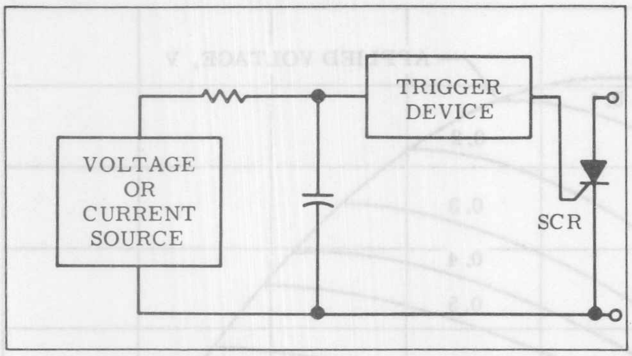

FIGURE 7 — RELAXATION OSCILLATOR SCR TRIGGER CIRCUIT

CONTROL CHARACTERISTICS

The simplest and most common control circuit for phase control is a relaxation oscillator. This circuit is shown diagramatically as it would be used with an SCR in Figure 7. The capacitor is charged through the resistor from a voltage or current source until the breakover voltage of the trigger device is reached. At that time, the trigger device changes to its "on" state, and the capacitor is discharged through the gate of the SCR. Turn-on of the SCR is thus accomplished with a short, high current pulse. Commonly used trigger devices are unijunction transistors, neon bulbs, and three, four, or five layer semiconductor trigger devices. Phase control of the output waveform is obtained by varying the RC time constant of the charging circuit so that the trigger device breakdown occurs at varying phase angles within the controlled half cycle.

If the relaxation oscillator is to be operated from a pure DC source, the capacitor voltage-time characteristic is shown in Figure 8 and Figure 9. Figure 8 shows the capacitor voltage as it rises all the way to the supply voltage through several time constants. Figure 9 shows the charge characteristic in the first time constant greatly expanded. It is this portion of the capacitor charge characteristic which is most often used in SCR control circuits.

Generally, a design starting point is selection of a capacitance value which will reliably trigger the SCR when the capacitor is discharged. SCR gate trigger characteristics and trigger device characteristics both play a part in the selection. Since not all of the important device characteristics for this selection are completely specified, experimental determination is often the best method.

Once a capacitor is selected, the curve of Figure 8 or Figure 9 may be used to determine the charging resistance necessary to obtain the desired control characteristics.

One note of caution should be injected at this point. Although many circuits begin each half cycle with the capacitor voltage at or near zero, some circuits leave a relatively large residual voltage on the capacitor after discharge (primarily neon lamp and three-layer semiconductor trigger circuits). In these latter circuits, the charging resistor must be determined on the basis of the additional charge necessary to raise the capacitor to trigger potential.

An example will demonstrate the procedure. Let us assume that we wish to trigger an 2N4154 SCR with a 32 volt 3-layer trigger. We have determined that a 0.1 μF capacitor will supply the necessary SCR gate current with the trigger diode. Assume a 50 volt DC power supply, 30° minimum conduction angle and 150° maximum conduction angle with a 60 Hz anode power source. The trigger diode triggers at approximately 32 volts and leaves

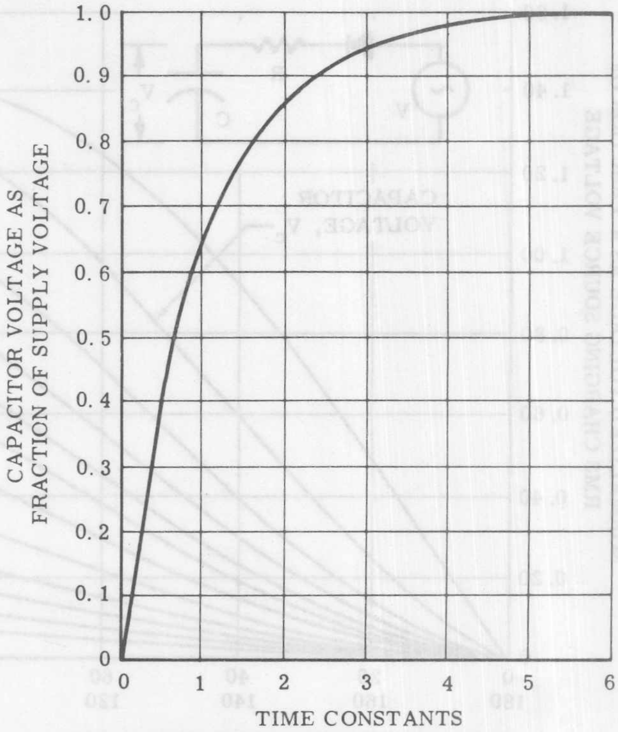

FIGURE 8 — CAPACITOR CHARGING FROM DC SOURCE

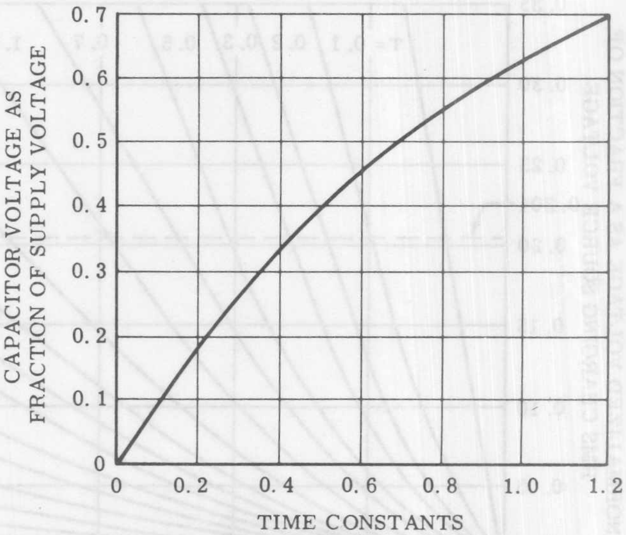

FIGURE 9 — EXPANDED SCALE OF FIGURE 8

10 volts on the capacitor after firing. Thus, 22 volts must be added to the capacitor potential in order to trigger, and 40 volts additional (50-10) are available. The capacitor must charge to 22/40 or 0.55 of the available charging voltage in the desired time. Referring to Figure 9, we see that 0.55 of charging voltage represents 0.8 time constant. The 30° conduction angle requires that the firing pulse be delayed 150° or 6.92 milliseconds. (8.33 milliseconds is the period of 1/2 cycle at 60 Hz.) To obtain this time delay,

$$6.92 \text{ ms} = 0.8 \text{ RC}$$

$$\text{RC} = 8.68 \text{ ms}$$

If C = 0.10 μF,

$$R = \frac{8.68 \times 10^{-3}}{0.1 \times 10^{-6}} = 86,800 \text{ ohms}$$

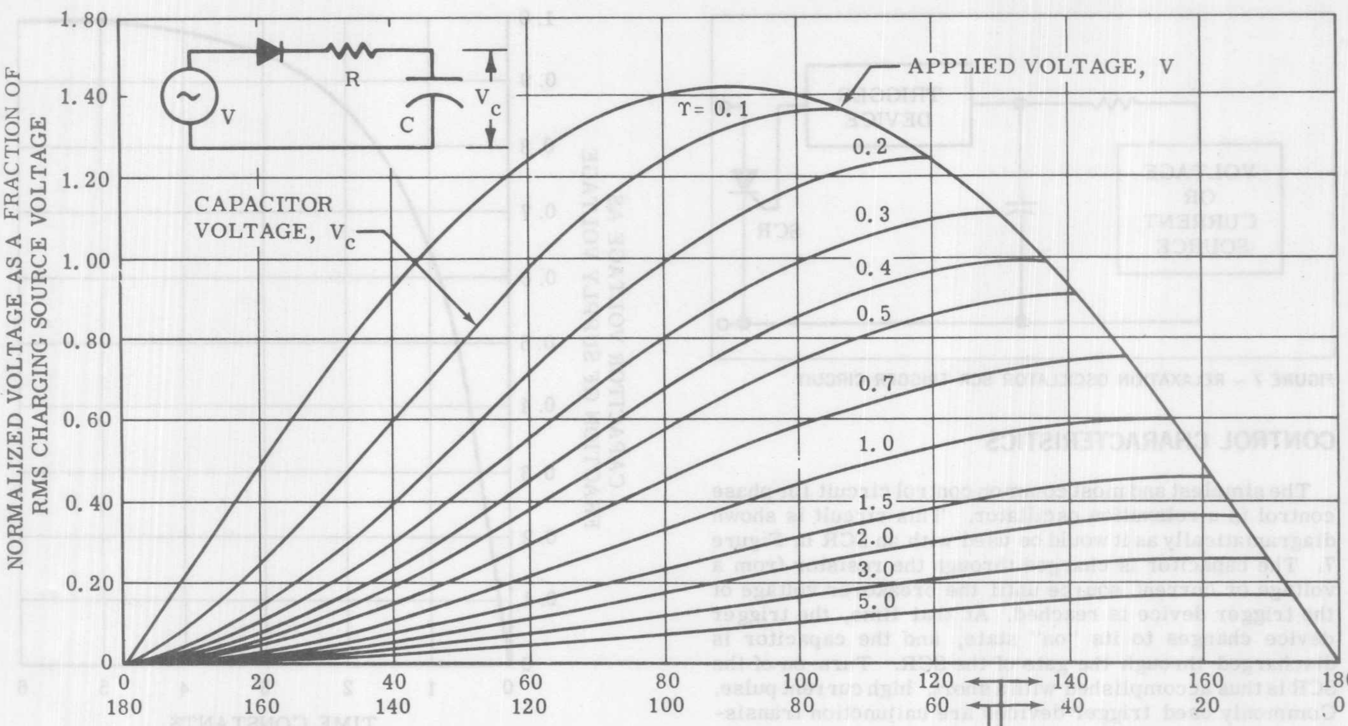

FIGURE 10 — CAPACITOR VOLTAGE WHEN CHARGED

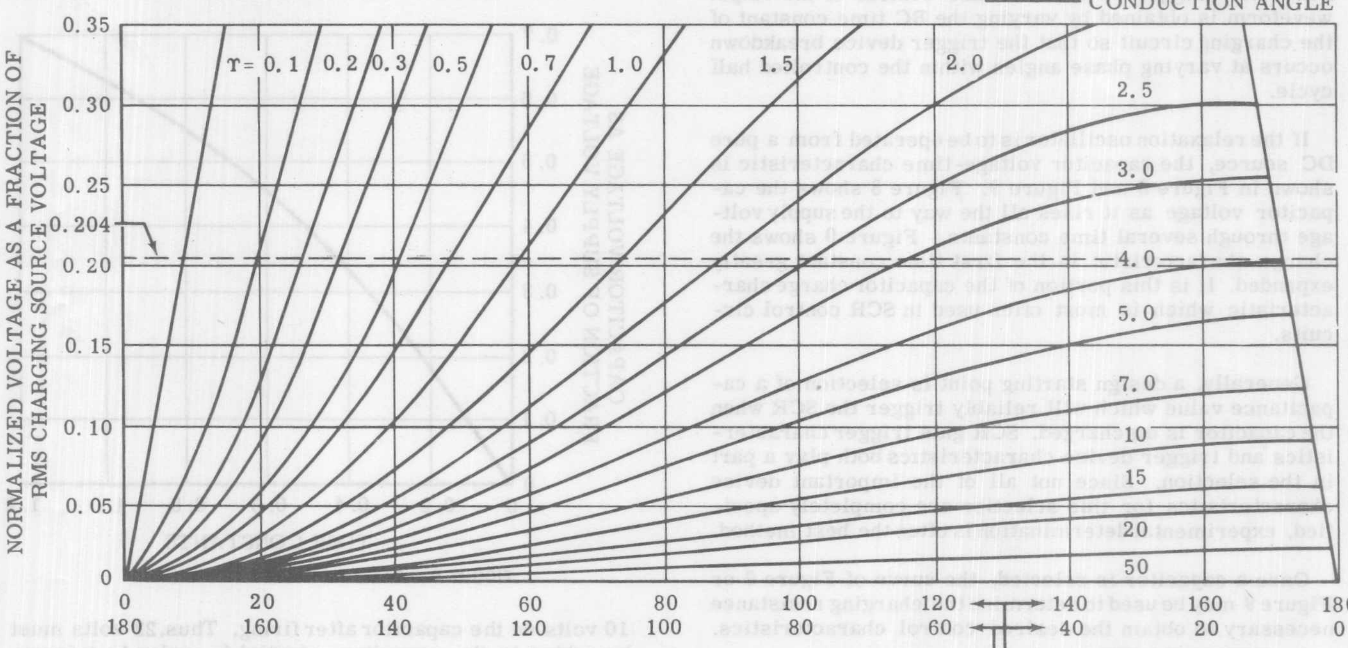

FIGURE 11 — EXPANSION OF FIGURE 10

To obtain minimum R, 150° conduction angle, the delay is 30° or

$$30/180 \times 8.33 = 1.39 \text{ ms}$$

$$1.39 \text{ ms} = 0.8\ RC$$

$$RC = 1.74 \text{ ms}$$

$$R = \frac{1.74 \times 10^{-3}}{0.10 \times 10^{-6}} = 17,400 \text{ ohms.}$$

Using practical values, a 100K ohm potentiometer with up to 17K minimum resistance, will serve this purpose. Similar calculations using conduction angles between the maximum and minimum values will give the control resistance versus power characteristic of this circuit.

In many of the recently proposed circuits for low cost operation, the timing capacitor of the relaxation oscillator is charged through a rectifier and resistor using the AC power line as a source. Calculations of charging time with this circuit become exceedingly difficult, although they are still necessary for circuit design. The curves of Figures 10 and 11 simplify the design immensely. These curves show the voltage-time characteristic of the capacitor charged from one half cycle of a sine wave. Voltage is normalized to the r.m.s. value of the sine wave for convenience of use. The parameter of the curves is a new term, the ratio of the RC time constant to the period of one half cycle, and is denoted by the Greek letter Υ. Υ may most easily be calculated from the equation

$\Upsilon = 2RCf.$ Where: R = resistance in Ohms
C = capacitance in Farads
f = frequency in Hertz

To use the curves when starting the capacitor charge from zero each half cycle, a line is drawn horizontally across the curves at the relative voltage level of the trigger breakdown compared to the r. m. s. sine wave voltage. The τ is determined for maximum and minimum conduction angles and the limits of R may be found from the equation for τ. If a trigger circuit which leaves residual voltage on the capacitor is used with a DC SCR circuit, the curves may be used with moderate accuracy by subtracting 0.71 times the residual voltage from the charging sine wave r. m. s. voltage, providing the residual voltage is less than 25% of the sine wave r. m. s. Ballpark estimates may be obtained with residual voltages as high as 50% of the sine wave r. m. s. using this method.

An example will again clarify the picture. Consider the same problem as the previous example, except that the capacitor charging source is the 115V AC, 60 Hz power line. Since the 10 volt residual charge is less than 25% of 115 volts, the curves will give us an acceptable result. Correcting the source voltage,

$$E_s = 115 - 0.71 \times 10 = 108 \text{ volts}$$

The ratio of the additional voltage necessary to break over the trigger diode to the equivalent r.m.s. changing voltage is then

$$22/108 = 0.204$$

A line drawn at 0.204 on the ordinate of Figure 11 shows that for a conduction angle of 30°, $\tau = 3.80$, and for a conduction angle of 150°, $\tau = 0.27$. Therefore, since

$$R = \frac{\tau}{2Cf}$$

$$R_{max} = \frac{3.8}{2 \times .01 \times 10^{-6} \times 60} = 316,000 \text{ ohms}$$

$$R_{min} = \frac{0.27}{2 \times 0.1 \times 10^{-6} \times 60} = 22,500 \text{ ohms}$$

These values would require a potentiometer of 300k ohms in series with a 22k minimum fixed resistance. Figure 12 shows a DC power control circuit capable of controlling a 600 watt load using the values just derived.

For AC design, 0.71 x the residual voltage is added to the line voltage, since on each half cycle the residual voltage from the previous half cycle is of opposite polarity to the applied voltage. Figure 13 shows an AC control circuit derived from that of Figure 12. To obtain full wave control, this circuit uses the bidirectional 3-layer trigger and a triac which allows triggering in both half cycles.

Incandescent lamps and some motors require full range control for maximum benefit. The circuit of Figure 14 was derived from that of Figure 13 and uses a double phase shift network to obtain reliable triggering at conduction angles as low as 5°.

SUMMARY

With new low SCR prices and simplified circuits, automatic control is a possibility for many electrical products in the consumer market. These simple circuits discussed in this paper will give the product designer a good feel for the nature of SCR circuits and their design. As he becomes more familiar with the control techniques, more sophistication, such as speed or temperature feedback circuits can be developed. The degree of control obtainable with very simple circuits using SCR's is a remarkable phenomenon. Consumer products will benefit greatly both in usability and marketability as a result.

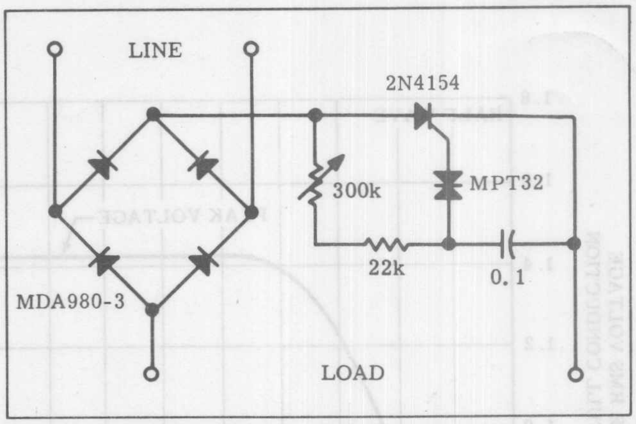

FIGURE 12 — SIMPLE DC POWER CONTROL CIRCUIT

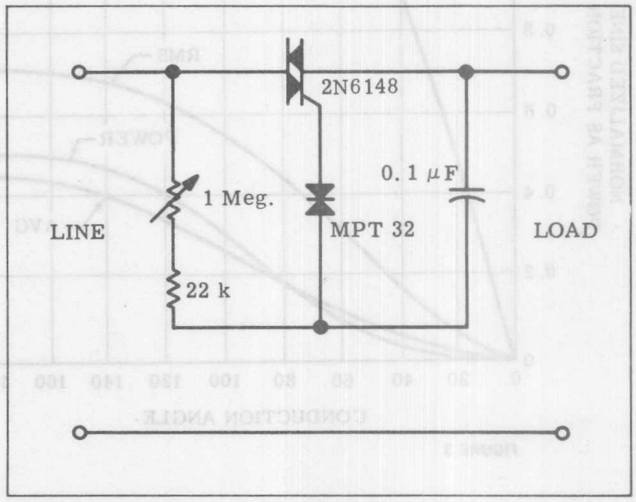

FIGURE 13 — SIMPLE FULL-WAVE POWER CONTROL

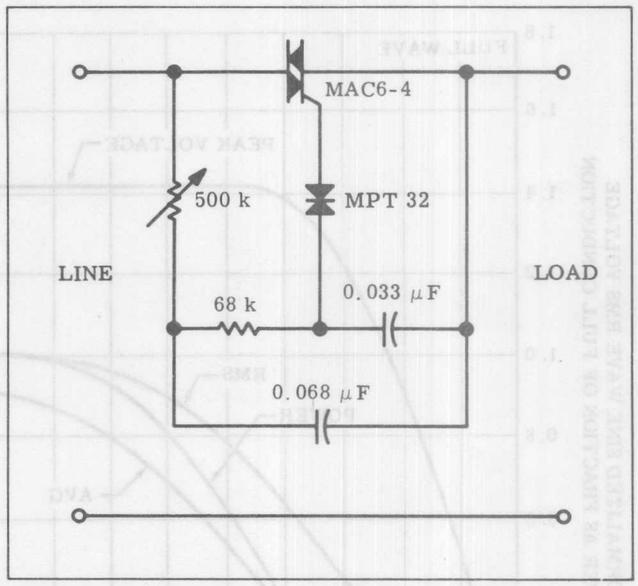

FIGURE 14 — FULL RANGE AC POWER CONTROL

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